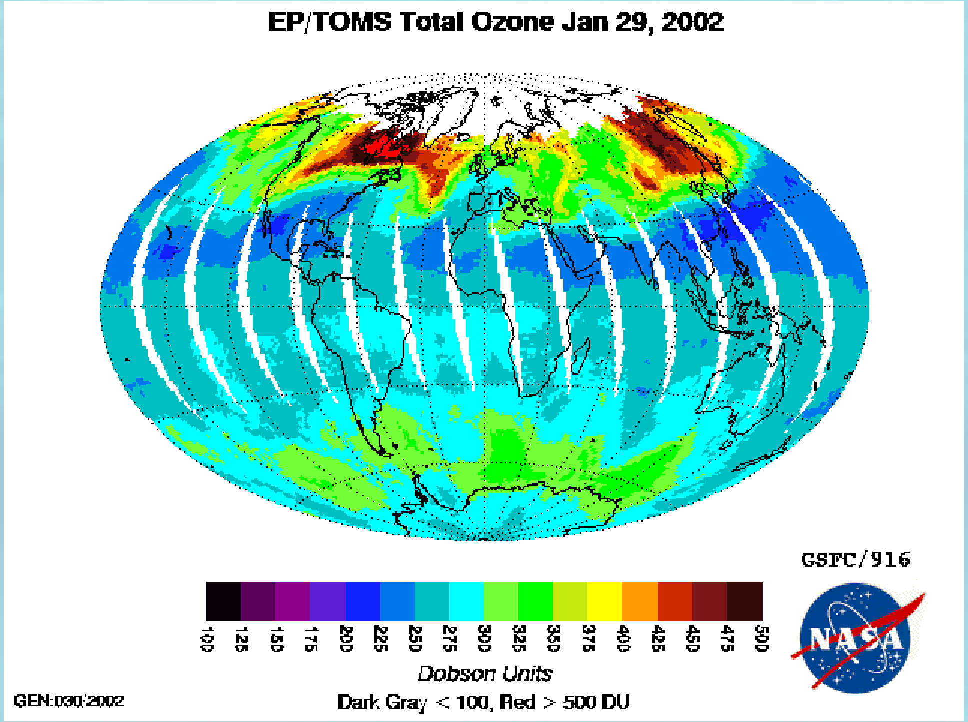
SCIENCE FOCUS: Ozone

O-Three, Can You See?



Global ozone concentration map for January 29, 2002. The map was created from data acquired by the Earth Probe - Total Ozone Mapping Spectrometer (EP-TOMS) instrument.

If they hear the word "ozone", the next word many people will think of is "hole", as in "ozone hole". The phrase "ozone hole" refers to the depletion of stratospheric ozone over the continent of Antarctica every winter, caused by the catalytic interaction of chlorofluorocarbons (CFCs) and ozone on the surfaces of ice particles high in the Antarctic polar vortex. The reason that numerous countries around the world are signatories to the Montreal Protocol which eliminates the use of CFCs is concern over the reduction of ozone concentrations in the stratosphere.

But when ocean color scientists hear "ozone", the next word they likely think of is "absorption", as in the absorption of light by ozone molecules. The presence of ozone in the atmosphere is one factor that must be corrected for in the process of producing accurate ocean color data.

Natural ozone (as opposed to ozone that forms from pollution in the troposphere) is formed when ultraviolet (UV) light from the sun provides energy that breaks a normal molecule of oxygen (O_2) into two oxygen atoms. These two oxygen atoms are highly reactive, and they can combine with another O_2molecule to form a molecule of ozone, O_3.

The chemical equations for the formation of ozone are thus (where *hv* represents a photon of UV light):

$$O_2 + hv \longrightarrow O + O$$

$$O_2 + O \longrightarrow O_3$$

Ozone in the stratosphere is particularly important for one reason: ozone molecules strongly absorb UV light, which is the light that causes sunburn on unprotected human skin. Ozone absorbs UV light by the "reverse" reaction:

$$O_3 + hv \longrightarrow O_2 + O$$

Below is a graphic illustration of the process, courtesy of Vito Ilacqua of the Rutgers University Institute of Marine and Coastal Sciences. The red spheres represent oxygen atoms.

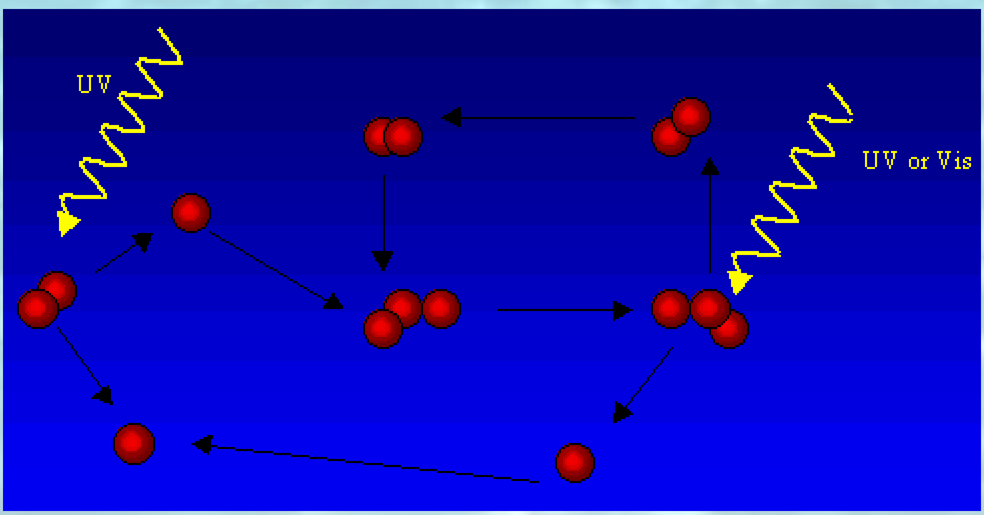
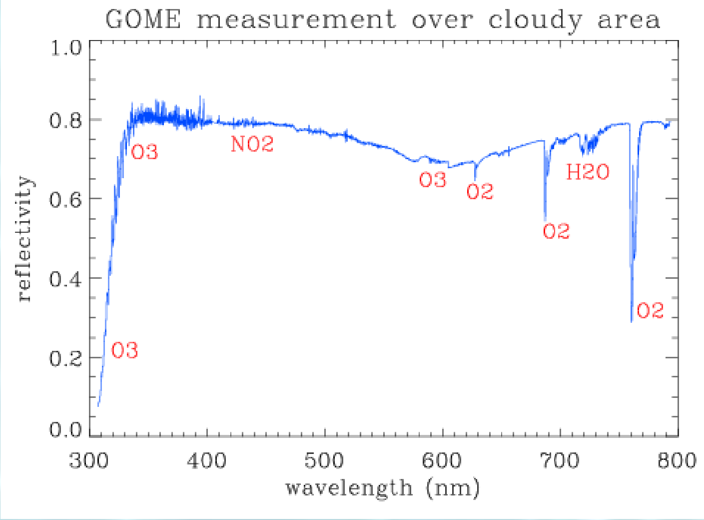


Illustration of the Chapman mechanism for ozone destruction and formation in the stratosphere.

UV light can cause damage to many other organisms, both plants and animals, and the potential for damage is what makes the protective ozone in Earth's stratosphere so important. The absorption of UV light by ozone also makes it fairly easy to measure its concentration in the atmosphere, which is what satellite instruments such as the Total Ozone Mapping Spectrometer (TOMS) and the TIROS Operational Vertical Sounder (TOVS) do quite well.

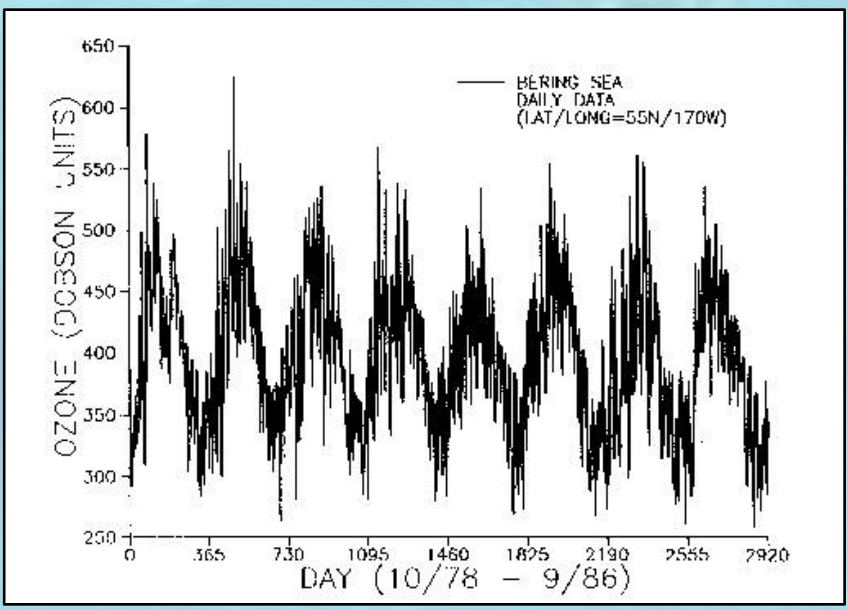
Perhaps overlooked in the emphasis on the absorption of UV light by ozone lesser-known fact that ozone also absorbs light in the visible portion of the electromagnetic spectrum. Even though ozone doesn't absorb much visible light, it is still necessary to correct for the absorption of light due to ozone in the atmospheric correction process for ocean color data (and for other varieties of remote sensing data).

In 1881, a few years after the discovery of ozone, W.N. Hartley hypothesized that the observed spectrum of UV light from the sun was influenced by the presence of ozone in the stratosphere. This spectrum was known as the "UV cutoff", because the spectrum of UV light is sharply attenuated. Hartley's supposition was confirmed by an individual named Chappuis, who also discovered the absorption of light by ozone in the visible range of the spectrum. The wavelength where ozone absorbs visible light is at 602 nm, and is called the "Chappuis band". (Unfortunately, that's about all we can learn about Mr. Chappuis!) The spectrum below, obtained by the Global Ozone Monitoring Experiment (GOME) instrument on the ERS-2 satellite, shows both the ozone cutoff and the Chappuis absorption band. (Spectrum courtesy of Dr. R.B.A. (Robert) Koelemeijer, Royal Netherlands Meteorological Institute.)



GOME data for gaseous absorption in the atmosphere. The Chappuis ozone absorption band appears at 602 nm.

The presence of the ozone hole in the Antarctic winter stratosphere is a drastic demonstration of how much ozone concentrations can vary. Another example, of changes in the concentration of ozone over the Bering Sea, is shown below. Ozone concentrations are expressed in "Dobson units", after Dobson (from the Clarendon Laboratory at Oxford University), who invented one of the first instruments for measuring ozone concentration based on its absorption of UV light.



Graph of ozone concentration (in Dobson units) variability over the Bering Sea during the CZCS mission period, October 1978- September 1986.

The significant variability of ozone concentration makes the atmospheric correction process a bit more difficult. Although the absorption of light by ozone in the visible range peaks at 602 nm, the presence of ozone influences both Rayleigh scattering and aerosol scattering of light in the atmosphere. These quantities are calculated in the atmospheric correction process, so if the value for ozone concentration used in the calculation is in error by a significant amount, the entire atmospheric correction process will be affected.

In order to perform the best atmospheric correction for ozone, the SeaWiFS Project uses daily data for ozone concentration which is acquired by the orbiting TOMS and TOVS instruments. The global ozone map shown at the top of this page illustrates what this data looks like. Because UV light destroys ozone, ozone concentrations will be higher near the poles during their respective winter months. One interesting note: most of the ozone found at high latitudes isn't formed there; it is actually formed near the Equator and transferred "poleward" by high-altitude winds.

In the map on the first page, high ozone concentrations are seen over Canada and Siberia. Ozone concentrations are lower in the tropics due both to atmospheric transport (described above) and because of the greater intensity of sunlight near the equator, which destroys ozone at a higher rate.

TOMS has been deployed on several satellites, such as Nimbus-7 (which also carried the Coastal Zone Color Scanner), the Upper Atmosphere Research Satellite (UARS), and the Earth Probe - TOMS (EP-TOMS) satellite, but the most recent attempt to put another TOMS instrument into orbit failed, and the EP-TOMS satellite is currently experiencing some problems. Fortunately, the TOVS instrument is one of the basic payload instruments on NOAA polar-orbiting environmental satellites, and this data should continue to be available if TOMS data is not. However, the importance of ozone data to the process of producing accurate ocean color data highlights the interdependence of many satellite remote sensing missions.

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Links:
- NPOESS/VIIRS Atmospheric Correction over Ocean (PDF)
- GOME: The Global Ozone Monitoring Experiment
- MSL12 User Document (MSl12 is the software in SeaDAS that processes SeaWiFS Level 1A data to Level 2. Ozone atmospheric transmittance can be calculated as an output product.)
- TOVS Total Ozone: Stuff You Should Know
- TIROS Operational Vertical Sounder
- NASA Goddard Ozone and Air Quality

References:
McClain, C.R., and Yeh, E-N., 1994: "SeaWiFS Ozone Data Analysis Study". Chapter 2 in Volume 13 of the SeaWiFS Pre-launch Technical Memorandum Series, *Case Studies for SeaWiFS Calibration and Validation, Part 1,* NASA Technical Memorandum 104566, S.B. Hooker and E.R. Firestone, Eds., pages 9-14.
Vasilkov, A., Krotkov, N., Herman, J., McClain, C.R., Arrigo, K., and Robinson, W., 2001: Global mapping of underwater UV irradiances and DNA-weighted exposures using Total Ozone Mapping Spectrometer and Sea-viewing Wide Field-of-view Sensor data products. *J. Geophys. Res.*, **106(C11),** 27,205-27,219.